

Goiran J.-Ph., Morhange C., 2001, "Geoarcheology of ancient mediterranean harbours: issues and case studies", eng. transl. E. Willcox, Topoi, vol. 11, fasc. 2, pp. 647-669.

## **GEOARCHEOLOGY OF ANCIENT MEDITERRANEAN HARBOURS**

### **Issues and case studies**

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**Keywords:** ancient harbour, harbour structure, harbour basin, sea level, geoarchaeology, palaeogeography, human impacts, Mediterranean.

#### **Abstract**

The geoarchaeological research of ancient harbours enables the study of relations between societies living by harbours and those of coastal environments. Research into harbour archaeology is still limited for several reasons. First of all, these studies are oriented more towards analysis of the great harbour cities rather than their harbour complexes. Secondly, the proximity of the body of seawater makes operations for pumping the water table difficult. Finally, often only the – harbour structures have attracted the interest of researchers at the expense of the associated marine stratigraphic units. A harbour basin is defined by three elements: a container (the structures: moles, wharves, posts...), a content (composed of accumulated sediments and a column of water above) and a water surface upon which ships circulate (sea level). Our approach takes these three elements into account and studies three types of problems. The question Where? deals with locating the harbours, whether immersed or buried beneath the sediments. The question When? enables definition of the chronological terms. The dates of foundation and abandonment are defined as well as the duration of the time that the harbour was functional. The question How? takes on the theme of the natural mobility of the coastal landscapes and the impacts of anthropization related to the emergence and development of harbour societies.

## Introduction

The ancient harbours contain excellent sedimentary and historical archives, because this type of sedimentary environment is artificially protected from the marine dynamics of the open sea. The sediments brought by rivers, wastewater networks, runoff and sea currents can be preserved in optimal conditions for thousands of years.

The archaeological excavation of a harbour basin poses many technical problems related to the omnipresence of the water table at sea level. Recourse to cast walls, evacuation of infiltrating water, instability of the terrain, for example, represent some of the many technical difficulties and high costs.

The implementation of a geoarchaeological approach, preliminary for any excavation, enables in most cases a better understanding of the coastal palaeoenvironment, the coastal morphodynamic processes and the organisational principles of an ancient harbour and urban area. The work of pioneers such as BOUSQUET *et al.* (1987) and RABAN (1985, 1988) can be cited. Reference can also be made to the more recent sedimentological studies of SCHRÖDER and BAY (1996) and BRUCKNER (1997) concerning the harbours of Ionia, the study by REINHARDT *et al.* (1998) on the palaeoenvironments of Caesarea (Israël), the overview study by Pirazzoli on the harbours of Phoenicia (1999), and the preliminary work of Duchêne *et al.* (2001) on the harbour landscape of ancient Delos.

With the experience gained on different types of harbour excavations in the eastern Mediterranean (programs carried out by the *Centre d'Etudes Alexandrines* in Egypt [GOIRAN 2001; EMPEREUR 1999], the French mission at Kition-Bamboula in Cyprus [MORHANGE *et al.* 1999; YON 2000], the excavation of the British museum at Sidon [DOUMET-SERHAL 2000]) and with reference to the bibliography, we present a preliminary study concerning the usefulness of geomorphological techniques for a better understanding of ancient harbour environments (*fig. 1*). This approach enables us to answer essential questions that are of interest to archaeologists, historians and geographers.

The first question that this approach can help to answer is **where**? This concerns locating harbour basins on archaeological sites. We will develop the examples at Alexandria in Egypt (GOIRAN 2001) on different scales: mobility of shorelines, attempt to locate a "lost harbour" such as that at Cumae in Campania (VECCHI *et al.* 2000).

The second issue to which we can provide answers is **when**? In the absence of costly stratigraphic excavation in countries that are often developing ones, study by archaeologists is sometimes limited to written sources interpreted in an unsatisfactory way and to excavations that are often old ones, such as the work of Dunand (1939) for Byblos or Poidebard for Tyre and Sidon (POIDEBARD and LAUFFRAY 1951; POIDEBARD 1939). Our chronological approach will enable definition of the duration of harbour constructions on Mediterranean coasts in ancient times.

A third question - **how?** - concerns the dynamics of harbour landscapes and the dynamics of palaeoenvironments. This vast theme consists of many aspects, such as the impact of anthropization on the geosystem: stress on biotic communities, detritic crises causing silting up, various urban and metallurgical pollutions...

## 1. Elements of definition and methodology

### 1.1 Definition of an ancient harbour

A harbour can be roughly defined, from a naturalist's point of view, by three elements: the container, the contents and the surface area of seawater (*fig. 2*).

- **the container**: this consists of archaeological structures cut into the substratum (for example, the harbours of cothon type attributed to the Phoenicians, such as Madhia in Tunisia) or constructions of enveloping mole type (Caesarea Maritima (HOLLUM *et al.* 1999) and the north harbour of Tyre). Because of the difficulty of excavation below sea level in contexts that are often very densely urbanised, these archaeological structures have rarely been excavated and studied, as they have been at Caesarea in Israel (HOLLUM *et al.* 1999) and Amathonte in Cyprus (EMPEREUR and VERLINDEN 1986; EMPEREUR 1995).

- **the sedimentary contents**: a typical harbour basin consists of an accumulation of stratigraphical layers usually composed of small argilo-silty particles of decantation, characteristic of a protected environment (MORHANGE 1994, 2001). We insist on the importance of these muddy sedimentary facies, which constitute a subject of archaeological research. Indeed, these fine deposits, which are indicative of a confined and protected harbour environment, contain much indications. We find for example many bio-indicators (fauna, pollen, seeds...) which provide information on the degrees of protection, of confinement and of degradation of the environment, as well as important archaeological material that is rarely preserved in oxidizing environments out of water, such as leather, wood (shipwrecks, posts...) and fibres, which provide invaluable evidence that can be well dated.

- **the water mass**: in contact with the two environments, terrestrial and marine, the harbour basin has recorded and been subjected to the relative variations in sea level, the rhythms of sedimentary deposit and the concomitant aggradation of the basin floor which in most cases results in partial or complete infilling of the harbour basin and even abandonment of the harbour in the case of rapid progradation, as occurred in the harbours of Ionia (BRUCKNER 1997) and the Bronze Age harbour of Enkomi in Cyprus (DEVILLERS *et al.* in press). Two dynamic interfaces should thus be definable: the sea level and the harbour floor.

This approach enables measurement of the height of the water column and an estimation of the maximal water displacement of the ships (100 cm in the 6<sup>th</sup> c. BC in the ancient harbour of Marseilles).

## **1.2 From the field to the laboratory: work methods**

The different stages of our study can be resumed as follows (*fig. 3*):

### **1.2.1 Surveys and geomorphological cartography**

This stage enables an initial zoning of the archaeological sites that are potentially the most interesting, depending upon the distribution of shapes on the terrain and superficial formations: band of dunes, depression behind the dunes, filled lagoon, fluvial morphology, ancient shoreline and dead cliff, following the work of Fouache (1999). This research is also based on the cartographic, iconographic and photographic archives available for the particular sector of study. In the case of submerged harbours, such as Alexandria or Tyre, surveying on land is coupled with scuba-diving in order to search for indicators of the relative variations in sea level: morphological (notches and erosion ledges), biological (levels at which fixed fauna such as oysters and barnacles are attached), endolithic fauna (lithophage molluscs as at Pozzuoli (MORHANGE *et al.* 1999). This work is complementary to the usual records made by the excavation team of the archaeological structures on land and under water. Beyond the archaeological zone, this work is coupled with research into the presence of bio-indicators of sea level such as ledges of western Mediterranean *Lithophylla* and platforms of western Mediterranean vermetid snails (LABOREL and LABOREL-DEGUEN 1994).

### **1.2.2 Geophysical surveys**

If the archaeological, geomorphological and biological information is too fragmentary, a team of geophysicists is called upon, which enables the establishment by appropriate techniques (geoelectricity, magnetometry, radar, seismic studies...) of geophysical profiles that are interpretable in stratigraphic and geoarchaeological terms (HESSE 2002). This cartography in three dimensions enables rough location of the artificial shorelines, of anomalies possibly corresponding to archaeological structures and of the ancient surface area of the water of the harbour, as at Cumae. We refer interested readers to the detailed article by HESSE *et al.* (1999) concerning the discovery of the location of the Heptastadium of Alexandria.

### **1.2.3 Borehole sampling**

By means of several complementary techniques of sampling by drilling boreholes (hand drill, mechanical rotary drill, stationary piston...), sedimentary columns were removed, the analysis of which will provide a better understanding

of the palaeoenvironments and the processes that occurred. These fossil deposits will be compared to a sedimentological frame of reference that will take into account the diversity of environments of sedimentation and systems of erosion. The sediments must of course be placed in cold store in order to avoid decomposition of the organic matter, which could lead to distortion of the isotope dating.

#### 1.2.4 Laboratory analyses

This stage is not to be carried out by an overall treatment of the samples by a single person, or by sending the samples to specialists of different disciplines within the life and earth sciences, who are not always aware of the geographic problems posed by the study of the site. It is necessary to put together a network of naturalists competent in particular disciplines who are interested in a multi-disciplinary discussion. According to the questions to be asked, different specialists in land and marine environments will be called upon (MISKOVSKY 2002).

Examination of the samples centimetre by centimetre enables obtainment of an exceptional chronological resolution because of the rapid sedimentation in harbour basins. For example, the speed of sedimentation was about 1 cm per year at Alexandria in the Greco-Roman period and 2 cm per year at Marseilles.

For the marine environment that interests us here, the main disciplines are malacology (PÉRÈS and PICARD 1964), micropalaeontology (HASLETT 2002), particularly the ostracods (BODERGAT 2002; CARBONEL 1991), the foraminifera (GEHRELS 2002) and the diatoms (GASSE 2002). In fact bio-indicators are the best evidence for determining the mode of the sea-lashed environment, the type of connection with the open sea and the degree of confinement (GUELORGET et PERTUISOT 1983). Concerning the lithographic fraction, granulometry and mineralogy can provide complementary indications for the sources of the sediments and the processes of transport and deposit of the particles.

The chronology is ensured by the comparison of dates obtained from the ceramic material with the radiocarbon dates obtained from organic material (shells *in situ*, charcoal, *Posidonia* fibres...). A problem often arises because of poor understanding of the "reservoir effect" of seawater in the Mediterranean (SIANI *et al.* 2001; REIMER and MCCORNAC 2002; ÉVIN 2002; ÉVIN *et al.* 1998; ÉVIN and OBERLIN 2001). Although the integration of cosmogenic radiocarbon into the atmosphere is almost immediate, the exchanges with the marine environment and within masses of water are more complex and less rapid. This results in a diminished content of radiocarbon for marine organisms. This aging is called the "reservoir effect". If a correction is not applied to the samples, the dates of the marine materials will present an aging or "apparent age" of about 400 years. In general, the zones in which marine currents rise from deep water and in which there are underwater karstic springs will produce dates older by several centuries. For example in Provence, at Carry-le-Rouet, two cerith shells (Ly-6898 et Ly-

6901) recovered in 1930 have an apparent age of  $1100 \pm 40$  BP (OBERLIN *et al.* 2001).

It is thus necessary to evaluate the apparent age of the seawater at the site studied by either measuring the shells collected alive before the effect of the first atomic explosions or by comparing on the same site the dates obtained from shells and from charcoal (ÉVIN and OBERLIN 2001). These samples are sometimes available in museums of natural history in the main cities of the Mediterranean area such as Milan, Naples or Marseilles.

We present three types of geoarchaeological questions to which our multidisciplinary approach can help to bring answers.

## 2. Where? A palaeogeographical problem

The first problem is to locate the harbour basins such as Cumae in Campania, the first western Greek colony. In a Franco-Italian research program under the direction of the Centre Jean Bérard, we have been able to show that the protected harbour is not located south-west of the acropolis as stated in the publications (SCHMIEDT 1966; PAGET 1968), but north of the archaic or early Greek harbour, along the shores of the lake of Licola (*fig. 4*); this was demonstrated by the argilo-silty borehole samples (thesis of L. Stéphaniuk, in progress) and the geophysical surveys carried out by A. Revil and M. Pessel. At Malia in Crete, the team directed by Dalongeville (2001) to find the Bronze Age harbour could only define a coastal marsh, contrary to the speculations of Raban (1991). In the Gulf of Corinth, the attempts of Soter and Katsonopoulou (1998) to find the engulfed city of Helike were unsatisfactory.

Another example is the Bronze Age harbour of Byblos located hypothetically by Frost south of the tell (FROST 2000; FROST and MORHANGE 2000). The Franco-Lebanese CEDRE campaigns of borehole sampling have shown that the bay south of Byblos was made up of environments of sandy sedimentation characteristic of tiny beaches open to the sea. If the harbour of "Wenhamoun" is located south of Byblos, it would have consisted of simple sandy beaches characteristic of an open harbour. Exploration by scuba diving in the summer of 2002 (COLLINA-GIRARD *et al.* in press) has provided evidence for the presence of an underwater relief off a promontory of Byblos, which could have protected the north harbour more than 5000 years ago. The question of the exact location of the Bronze Age harbour of Byblos thus remains open; the discovery of spectacular archaeological structures must not be expected, but rather beaches equipped with light structures.

On a larger scale, the shores are characterised by high mobility in a context of deceleration in the relative rise of sea level over the last 6000 years, and a largely positive sediment budget since clearing took place in the Neolithic. For

example, the northern harbour of Sidon is situated mostly under the modern and medieval city (ESPIC *et al.* 2002). This very general evolution represents an archaeological opportunity. In fact, the ancient shores are usually to be found within the urban fabric itself, such as the horn of the harbour of Marseilles or the haulage ramps of Piraeus or of Kition-Bamboula at Larnaka. Figure 5 presents the progressive retreat of the body of water along the north shore of the old harbour of Marseilles since the Bronze Age. The shoreline has advanced towards the sea more than 100 meters between this period and the modern era. This dynamic was accelerated in the Roman period. Thanks to the creation of an underground parking area or urban facilities, an archaeological excavation is possible in an urbanised environment. This historical progradation of shorelines, terrigenous in origin, is related to fluvial infilling and to modifications of clay from the fusion of dwellings in adobe.

On a small scale, the presence of islands results in a diffraction of the waves, which generates a morphology of tombolo type at the edge of deltas such as the peninsula of Alexandria-Pharos, Olbia-Giens, Tyre or Orbetello. The regularisation of the deltaic shoreline and the lengthening of an arrow in sheltered zones (Nir 1996) results in the segmentation of the bays and the creation of two very different natural harbours: one relatively agitated that faces the wind, the other beneath the wind that is particularly protected and favourable to the establishment of an ancient harbour that is naturally protected (GOIRAN 2001).

At Cyprus, during the archaeological excavation of the harbour of Kition-Bamboula at Larnaka, we were able to reveal several phases of modification of the shorelines over 3000 years. A protected marine gulf had at first served as a harbour zone in the late Bronze Age, in the middle of the 2<sup>nd</sup> millennium BC. Beginning in the 1<sup>st</sup> millennium BC, the environment became a lagoon environment and enabled the establishment of a closed war harbour. In late Antiquity, the environment corresponded to a hypersaline coastal lagoon that was to become infilled. Finally, the coastal marshes were improved by the British administration and the line of the coast completely modified artificially. This example illustrates the palaeogeographic problem of the connection between the lagoons and the sea (*fig. 6*). The recognition of an inlet or a channel by borehole sampling is both essential and particularly difficult (MORHANGE *et al.* 1999, 2000).

### 3. When? A chronological problem

A stratigraphical approach enables the answering of two fundamental chronological questions (*fig. 7*). The first concerns the date of construction of the basin, otherwise called the transition of a "natural" coastal environment to an environment that is more and more modified in its role as a harbour. The second

corresponds to the date of its abandonment, the point at which the basin is no longer functional and when the breakwaters no longer artificially protect the milieu.

The usual stratigraphy observed on most of the sites provides three principal units (*fig. 4*):

- At the base, a layer of shelly marine sand characteristic of open beaches and sectors crossed by currents.

- Then, we observe a muddy milieu typical of a closed harbour that is protected and confined. The change in facies, often abrupt, shows the rapidity of the establishment of archaeological structures for coastal protection.

- Finally, the highest layers often correspond to coarse shelly sands deposited after the maintenance of the harbour structures has been abandoned. The study of the change in facies provides indications on the nature and the speed of the abandonment of the harbour. The changes could have been progressive or sudden, natural (infilling as at Troy [KRAFT *et al.* 1980], due to subsidence as at Alexandria [GOIRAN 2001] and at Menouthis [STANLEY *et al.* 2001], due to upthrust as at Phalasarna [PIRAZZOLI 1992] or artificial (poor maintenance of the structures, land reclamation as at Tyre, conflicts...)

The dates refer to the base and the top of the muddy layer. The often abundant archaeological material provides a first series of dates which are compared with the C14 results obtained on shells and charcoal.

Finally, a last piece of information can be extracted from these sedimentary archives, the revelation of the phases of cleaning out the basins. As the rate of sedimentation was often high, the rise of the sea floor tended to make access difficult to the quays for ships with a high draught. Thus, for a ship of the open sea with a cargo of about 650 metric tons, the draught would be between 3 and 3.5 m. For a coastal ship measuring 20 m long on average, the draft would be about 1.5 m (pers. comm. J.-M. Gassend).

The cleaning-out phases demonstrate the will to maintain the harbour basins in a functional state. Different bio-indicators indicate cleaning phases that caused sedimentary and ecological disturbance of the milieu. Analysis of the micro-faunal content shows the abundance of opportunistic ostracods that colonise disturbed environments. Pioneering fauna develop rapidly when the ecological conditions of the milieu become degraded. The over-representation of a species indicates ecological stress related to dredging (causing the sediment to move, mixing of the waters, organic matter in suspension...). Finally, the archaeological and radiocarbon dates reveal one or more large chronological jumps that indicate gaps in the sedimentary archives.

#### **4. How?**

The determination and quantification of anthropization or human impact in the establishment of urban areas and harbours will enable definition of the forms



of spatial occupation and of the principal human activities. The objective is to characterise and to quantify these impacts on the environment, such as detrital crises that cause silting up and urban or metallurgical pollution. This involves going back over the phases and forms of the occupation of a littoral and measuring the first factors of impact of the societies on their environment. The construction of a harbour causes clear disturbance in the marine environment. When a "natural" coastal space is modified, five main types of impact can be detected in the sediments (*fig. 8*):

- **The first type of impact, seen in the granulometry**, causes a clear change in the size of the grains by enrichment in fine particles. The building of harbour structures results in the transition from an active marine mode to a calm mode. The harbour basin corresponds to a milieu of artificial sedimentation that traps the silty-clayey fractions.

- **The detrital impact** is defined by speeds of accelerated accumulation. For example, the archaic harbour of Marseilles silted up rapidly with sedimentation speeds of 20 mm per year (MORHANGE 1994). In comparison, the rate of sedimentation in the eastern harbour of Alexandria reached an average speed of 15 mm per year for the Greco-Roman period (GOIRAN *et al.* 2000).

- **The geomorphological impact** is probably the most visible in the landscape. Large volumes of terrigenous material, related in part to "urban" erosion events or from the basin itself, lead to the rapid advance of the beaches. These progradations are quantifiable, 4 km for the ria of Enkomi, several dozen kilometres for the coasts of Ionia (SCHRÖDER *et al.* 1996).

- **Biologically**, a double disruption affects the micro-fauna and micro-flora. There is a transformation from assemblages characteristic of environments open to the sea to assemblages adapted to a confined environment, rich in fine sediments. The impact of an often abrupt transition from one environment to another is seen quantitatively in a decrease of the number of species and an increase in the number of individuals. This tendency indicates ecological stress.

- **Geochemical impact** is characterised by the rejection into the sea of heavy metals from metallurgical activities. At Alexandria, we have used lead as a geochemical indicator of societies of Antiquity. This enables us to make progress in the interpretation of the occupation phases of the coastal area. In the 4<sup>th</sup> century BC, from the time of the creation of the city by Alexander, the results show a high peak in the presence of lead. However, a first sign of lead has been detected beginning already in the middle of the 3<sup>rd</sup> millennium BC. This first evidence, starting in 2400 BC, could indicate metallurgical activities nearby. These first elements enable modification of the idea of the urban creation *ex*

*nihilo* of Alexandria and raise the problem of the occupation of the site before the Hellenistic period (GOIRAN 2001). This question is particularly complex. It involves the differentiation of geochemical pollution brought about by ancient human occupation along the coasts of the lagoon and of the Mediterranean from that brought about by the foundation of the new city by Alexander. The problem concerns both the chronology and the degree and types of impact.

### Conclusion

Our studies have revealed the importance for archaeology of this line of research on ancient harbours. In the history of human occupation of the coasts of the Mediterranean, the foundation of harbours corresponds to an important point in time, when the coastal landscapes stopped evolving in a natural manner and were transformed and urbanised in ways that had no precedent. Recorded in the bio-sedimentary archives of the coastal environments are the degrees and the types of human impact on the environments, which correspond to the different ways space was organised during historical times. As in all geosystems, this concerns complex combinations, each category moving at its own rhythm from the long period (mobility of the landscapes) to the short period (instability, break, event...) (BOUSQUET *et al.* 1983).

With the passage of time, harbour sites were to multiply and to constitute a wide network enabling the maritime façades of the Mediterranean to interact over several millennia (GRAS 1995). We stress the fact that the methods of interference of societies in the environments were very different. The results show in fact highly varied levels of artificialization which correspond to specific ways of organising territory (PROVANSAL *et al.* 1995). It is necessary to study the relations between the evolution of coastal palaeo-environments and the dynamics of the societies of Antiquity. This history also reflects the weight of the natural constraints and the limits to the answers that the societies could provide. Thus, the duration of the harbour structures illustrates the difficulties involved in mastering a coast for the societies of Antiquity. This reflection reveals the work that is necessary to study the degree of artificialisation of the Mediterranean coast and the need to establish a typology of impacts for the different forms of harbour cities and their occupation of the environment. A comparative study of the harbour hierarchies and the impacts is in progress (doctoral thesis of N. Carayon on Phoenician and Punic harbours).

This research enables advancement of our understanding of ancient harbours and favours the development of an innovative and promising approach. It is a contribution to the study of the roles of societies over time in the management of their environment and the mobility of coastal landscapes. Our major intention here is to show the importance of the combined application of different approaches, geomorphological, sedimentological and biological, to the archaeological study of ancient harbours. This is thus "another history" that we

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are attempting to write. Our intention is not to illustrate the idea that the analysis of sediments is not only a contribution to archaeology but that it has become a subject of archaeological research.

### Acknowledgments

The authors extend thanks to the Ecole Française d'Athènes and the Ecole Française de Rome for having enabled them to complete and enrich the bibliographical references on ancient harbours of the Mediterranean.

### Bibliography

BODERGAT 2002

A.M. BODERGAT, « L'ostracode, sa signification en terme d'environnement », in MISKOVSKY 2002

BOUSQUET *et al.* 1983

B. BOUSQUET, J.-J. DUFAURE, P.-Y. PECHOUX, « Temps historiques et évolution des paysages égéens », *Méditerranée* 2, p. 3-25.

BOUSQUET *et al.* 1987

B. BOUSQUET, J.-J. DUFAURE, P.-Y. PECHOUX, « Ports antiques et lignes de rivage égéennes », in *Déplacements des lignes de rivage en Méditerranée d'après les données de l'archéologie, Colloque international du CNRS, Aix-en-Provence 1985*, Paris, p. 137-154.

BRUCKNER 1997

H. BRUCKNER, « Coastal changes in western Turkey; rapid progradation in historical times », in F. BRIAND et A. MALDONADO eds., *Transformations and evolution of the Mediterranean coastline*, CIESM Science Series, *Bulletin de l'Institut Océanographique* 18, Monaco, p. 63-74.

CARBONEL 1991

P. CARBONEL, « Les ostracodes du Paleolac Haïjad », in : *Paléoenvironnements du Sahara*, p. 91-100.

COLLINA-GIRARD *et al.* sous presse

J. COLLINA-GIRARD, H. FROST, M. HELOU, B. NOURREDINE, « Un promontoire sous-marin au large du port antique de Jbayl-Byblos : cartographie, interprétation géologique et implication archéologiques », *BAAL*.

DALONGEVILLE 2001

R. DALONGEVILLE et coll., « Malia : un marais parle », *BCH* 125, p. 67-88.

DEVILLERS *et al.* sous presse

B. DEVILLERS, C. MORHANGE, M. BUFFIERE DE L'AIR, M. BOURCIER, M. PROVANSAL, *Détritisme, potentialités et aménagements du territoire à l'Age du Bronze sur les secteurs amont (Potamia-Agios Sozomenos) et aval (Messarée orientale, secteur d'Enkomi-Acheritou) du bassin versant du Gialias (Chypre)*, avancement du programme POTAMIA.

DOUMET-SERHAL 2000

Cl. DOUMET-SERHAL, *Sidon, National Museum News* 10.

DUCHENE *et al.* 2001

H. DUCHENE, R. DALONGEVILLE, P. BERNIER, « Transformations du paysage naturel et évolution du littoral dans l'archipel délien », in H. DUCHENE et Ph. FRAISSE eds, *Le paysage portuaire de la Délos antique*, EAD 39, p. 165-176.

Goiran J.-Ph., Morhange C., 2001, "Geoarcheology of ancient mediterranean harbours: issues and case studies", eng. transl. E. Willcox, *Topoi*, vol. 11, fasc. 2, pp. 647-669.

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J.-P. GOIRAN - C. MORHANGE

DUNAND 1939

M. DUNAND, *Fouilles de Byblos I, 1926-1932*, Paris, 2 vols.

EMPEREUR 1995

J.-Y. EMPEREUR, « Le port hellénistique d'Amathonte », in V. KARAGEORGHIS, D. MICHAELIDES éds, *Proceedings of the International Symposium : Cyprus and the sea*, p. 131-137.

EMPEREUR 1999

J.-Y. EMPEREUR, « Alexandrie (Égypte) », *BCH* 123, « Études Chroniques et rapports », p. 545-559.

EMPEREUR - VERLINDEN 1986

J.-Y. EMPEREUR, C. VERLINDEN, « The underwater excavation at the Ancient Port of Amathus », *IJNA* 15-4, p. 1-13.

EMPEREUR *et al.* 2002

J.-Y. EMPEREUR, K. ESPIC, C. MOHRANGE, M. BOURCIER, C. BRUZZI, P. CARBONEL, CL. DOUMET-SERHAL, « Les ports antiques de Sidon : nouvelles données paléo-environnementales », *Archaeology and History in Lebanon* 15, p. 28-36.

ÉVIN 2002

J. ÉVIN, « Le radiocarbone » in MISKOVSKY 2002, p. 1183-1196.

ÉVIN *et al.* 1998

J. ÉVIN, A. FERDIERE, G.-N. LAMBERT, L. LANGOUËT, P. LANOS, C. OBERLIN, *La datation en laboratoire*.

ÉVIN et OBERLIN 2001

J. EVIN - C. OBERLIN, « Les développements récents en datation par le radiocarbone pour l'archéologie », in *Datation, XXI<sup>e</sup> rencontres internationales d'archéologie et d'histoire d'Antibes*, p. 93-111.

FOUACHE 1999

É. FOUACHE, *L'alluvionnement historique en Grèce Occidentale et au Péloponnèse*, *BCH* Supplément 35.

FROST 2000

H. FROST, « From Byblos to Pharos : some archaeological considerations », in *Underwater archaeology and coastal management sourcebooks* 2, UNESCO, p. 64-68.

FROST et MORHANGE 2000

H. FROST, C. MORHANGE, « Proposition de localisation des ports antiques de Byblos (Liban) », *Méditerranée* 1-2, p. 101-104.

GASSE 2002

F. GASSE, « Diatomée, archéologie et préhistoire » in MISKOVSKY 2002, p. 735-750.

GEHRELS 2002

W.R. GEHRELS, « Intertidal Foraminifera as Palaeoenvironmental indicators », in S.K. HASLETT ed., *Quaternary Environmental Micropalaeontology*, Londres, p. 91-114.

GOIRAN 2001

J.-P. GOIRAN, *Recherches géomorphologiques dans la région littorale d'Alexandrie en Égypte*, Thèse de Doctorat en Géographie Physique, Université de Provence, Aix-Marseille I, 264 p.

GOIRAN *et al.* 2000

J.-P. GOIRAN, C. MORHANGE, M. BOURCIER, P. CARBONEL, C. MORIGI, « Évolution des rivages d'Alexandrie à l'Holocène récent, marge occidentale du delta du Nil, Égypte », *Méditerranée* 1-2, Tome 94, p. 83-90.

GRAS 1995

M. GRAS, *La Méditerranée archaïque*.

Goiran J.-Ph., Morhange C., 2001, "Geoarcheology of ancient mediterranean harbours: issues and case studies", eng. transl. E. Willcox, Topoi, vol. 11, fasc. 2, pp. 647-669.

GUELORGET - PERTUISOT 1983

O. GUELORGET - J.-P. PERTUISOT, *Le domaine paralique, expressions géologiques, biologiques et économique du confinement*, Travaux du labo. de Géologie 16.

HASLETT 2002

S.K. HASLETT, ed., *Quaternary Environmental Micropalaeontology*, Londres.

HESSE *et al.* 1999

A. HESSE, P. ANDRIEUX, M. ATYA, C. BENECH, C. CAMERLYNCK, M. DEBAS, C. FECHANT, A. JOLIVET, C. KUNTZ, P. MECHLER, C. PANISSOD, L. PASTOR, A. TABBAGH, J. TABBAGH, « L'Heptastade d'Alexandrie », *Études Alexandrines*.

HESSE 2002

A. HESSE, « Méthodes géophysiques de la prospection » in MISKOVSKY 2002.

HOLUM *et al.* 1999

K.G. HOLUM, A. RABAN et J. PATRICH, eds, 1999, *Caesarea Papers 2, Journal of Roman Archaeology*, Supp. Series 35.

KRAFT *et al.* 1980

J.C. KRAFT, I. KAYAN, O. EROL, « Geomorphic reconstructions in the environs of ancient Troy », *Science* 209, p. 776-781.

LABOREL - DEGUEN 1994

J. LABOREL, F. LABOREL-DEGUEN, « Biological indicators of relative sea level variations and of co-seismic displacements in the Mediterranean region », *Journal of Coastal Research* 10-2, p. 395-415.

MISKOVSKY 2002

J.-C. MISKOVSKY, *Géologie de la préhistoire*, GEOPRE, Presse Univ. de Perpignan.

MORHANGE 1994

C. MORHANGE, *La mobilité récente des littoraux provençaux*, Thèse de Doctorat en Géographie Physique, Université de Provence, Aix-Marseille I, 269 p. et ann.

MORHANGE 2001

C. MORHANGE, *Mobilité littorale de quelques sites portuaires antiques de Méditerranée : Marseille, Pouzzoles, Cumes, Kition et Sidon*, Diplôme d'Habilitation à Diriger des Recherches, Université de Provence, Aix-Marseille I, 180 p. et ann.

MORHANGE *et al.* 1999

C. MORHANGE, J.-P. GOIRAN, M. BOURCIER, P. CARBONEL, J. LE CAMPION, B. PYATT, A. PRONE, J.-M. ROUCHY, J.-C. SOURISSEAU, M. YON, « 3000 ans de modification des environnements littoraux à Kition-Bamboula, Larnaca, Chypre, Méditerranée », *Quaternaire* 10, n°2-3, p. 133-149.

MORHANGE *et al.* 2000

C. MORHANGE, J.-P. GOIRAN, M. BOURCIER, P. CARBONEL, J. LE CAMPION, J.-Y. ROUCHY, M. YON, « Recent Holocene Paleo-environmental evolution and coastline changes of Kition, Larnaca, Cyprus, Mediterranean sea », *Marine Geologie* 170, p. 205-230.

NIR 1996

Y. NIR, « The city of Tyre, Lebanon and its semi-artificial tombolo », *Geoarcheology* 11/3, p. 235-250.

OBERLIN *et al.* 2001

C. OBERLIN, C. MORHANGE, V. PELC, E. DELQUE-KOLIC, « Influence de l'âge apparent local de l'eau de mer sur les datations des sites côtiers », in N. FLORSCH, éd., *Archéologie et archéométrie littorale et sous-marines, actes du colloque d'archéométrie*, La Rochelle, avril 2001, à paraître.

PAGET 1968

R.F. PAGET, « The ancient port of Cumae », *Journal of Roman Studies* 58, 1-2, p. 148-169.

Goiran J.-Ph., Morhange C., 2001, "Geoarcheology of ancient mediterranean harbours: issues and case studies", eng. transl. E. Willcox, *Topoi*, vol. 11, fasc. 2, pp. 647-669.

PERES - PICARD 1964

J.-M. PERES, J. PICARD, *Nouveau manuel de bionomie benthique de la mer Méditerranée*, *Rec. Trav. Stat. Marine Endoume*, Bull. 31, fasc. 47.

PIRAZZOLI 1999

P.A. PIRAZZOLI, « Les ports antiques soulevés de la Méditerranée orientale », *Geoarqueologia i Quaternari litoral, Memorial M.P. Fumanal*, Universitat di Valencia, p. 391-401.

PIRAZZOLI *et al.* 1992

P.A. PIRAZZOLI, J. AUSSEIL-BADIE, P. GIRESE, E. HADJIDAKI, M. ARNOLD, « Historical environmental changes at Phalasarna harbor, West Crete », *Geoarcheology, An International Journal* 7, p. 371-392.

POIDEBARD 1939

A. POIDEBARD, « Un grand port disparu : Tyr, recherches aériennes et sous-marines 1934-1936 », Paris, 2 vol.

POIDEBARD - LAUFFRAY 1951

A. POIDEBARD, J. LAUFFRAY, *Sidon, aménagements antiques du port de Saïda, étude aérienne, au sol et sous-marine (1946-1950)*, République libanaise, Ministère des Travaux Publics, Beyrouth.

PROVANSAL *et al.* 1995

M. PROVANSAL, C. MORHANGE, C. VELLA, « Impacts anthropiques et contraintes naturelles sur les sites portuaires antiques de Marseille et de Fos. Acquis méthodologiques », *Méditerranée* 3-4, p. 93-100.

RABAN 1985

A. RABAN (Ed), *Harbour archeology, Proceedings of the first international workshop on ancient Mediterranean harbours, Caesarea Maritima, 1983*, BAR International series 257.

RABAN 1988

A. RABAN, ed, *Archeology of coastal changes, Proceedings of the first international symposium "cities on the sea-past and present", Haifa, 1986*, BAR International series 404.

RABAN 1991

A. RABAN, « Minoan and Cananite harbours », *Aegaeum* 7, p. 129-146.

REIMER et McCORMAC 2002

P.J. REIMER, F.G. McCORMAC, « Marine radiocarbon reservoir corrections for the Mediterranean and Aegean seas », *Radiocarbon* 44/1, p. 159-166.

REINHARDT *et al.* 1998

E.G. REINHARDT, R.T. PATTERSON, J. BLENKINSOP, A. RABAN, « Paleoenvironmental evolution of the inner basin of the ancient harbor at Caesarea Maritima, Israel ; foraminiferal and Sr isotopic evidence », *Revue Paléobiol.*, Genève, 17-1, p. 1-21.

SCHMIEDT 1966

G. SCHMIEDT, « Antichi porti d'Italia. I porti delle colonie greche », *l'Universo* 46-2, p. 297-253.

SCHRÖDER et BAY 1996

B. SCHRÖDER, B. BAY, « Late Holocene Rapid Coastal Change in Western Anatolia – Büyük Menderes plain as a case study », *Z. Geomorph. N. F.* 102, p. 61-70.

SIANI *et al.* 2001

G. SIANI, M. PATERNE, M. ARNOLD, E. BARD, B. METIVIER, N. TISNERAT, F. BASSINOT, « Radiocarbon reservoir ages in the Mediterranean sea and Black sea », *Radiocarbon* 42/2, p. 271-280.

SOTER - KATSONOPOULOU 1998

Goiran J.-Ph., Morhange C., 2001, "Geoarcheology of ancient mediterranean harbours: issues and case studies", eng. transl. E. Willcox, *Topoi*, vol. 11, fasc. 2, pp. 647-669.

S. SOTER, D. KATSONOPOULOU, « The search for ancient Helike, 1988-1995 : Geological, Sonar and bore hole studies », in D. KATSONOPOULOU, S. SOTER, éds, *Ancient Helike and Aigialeia*, Athènes, p. 68-114.

STANLEY *et al.* 2001

D.J. STANLEY, F. GODDIO, G. SCHNEPP, « Nile flooding sank two ancient cities », *Nature* 412, p. 293-294.

VECCHI *et al.* 2000

L. VECCHI, C. MORHANGE., P.F. BLANC, J.-P. GOIRAN, M. BUI THI, M. BOURCIER, P. CARBONEL, A. DEMANT, F. GASSE, M. GIRARD, E. VERRECCHIA, « La mobilité des milieux littoraux de Cumes, Champs Phlégréens, Campanie, Italie du sud », *Méditerranée* 1-2, p. 71-82.

YON 2000

M. YON, « Les hangars du port Chypro-Phénicien de Kition : campagnes 1996-1998 (Mission Française de Kition-Bamboula) », *Syria* 77, p. 95-116.

Figure 1: map of the ancient Mediterranean harbours cited in this article

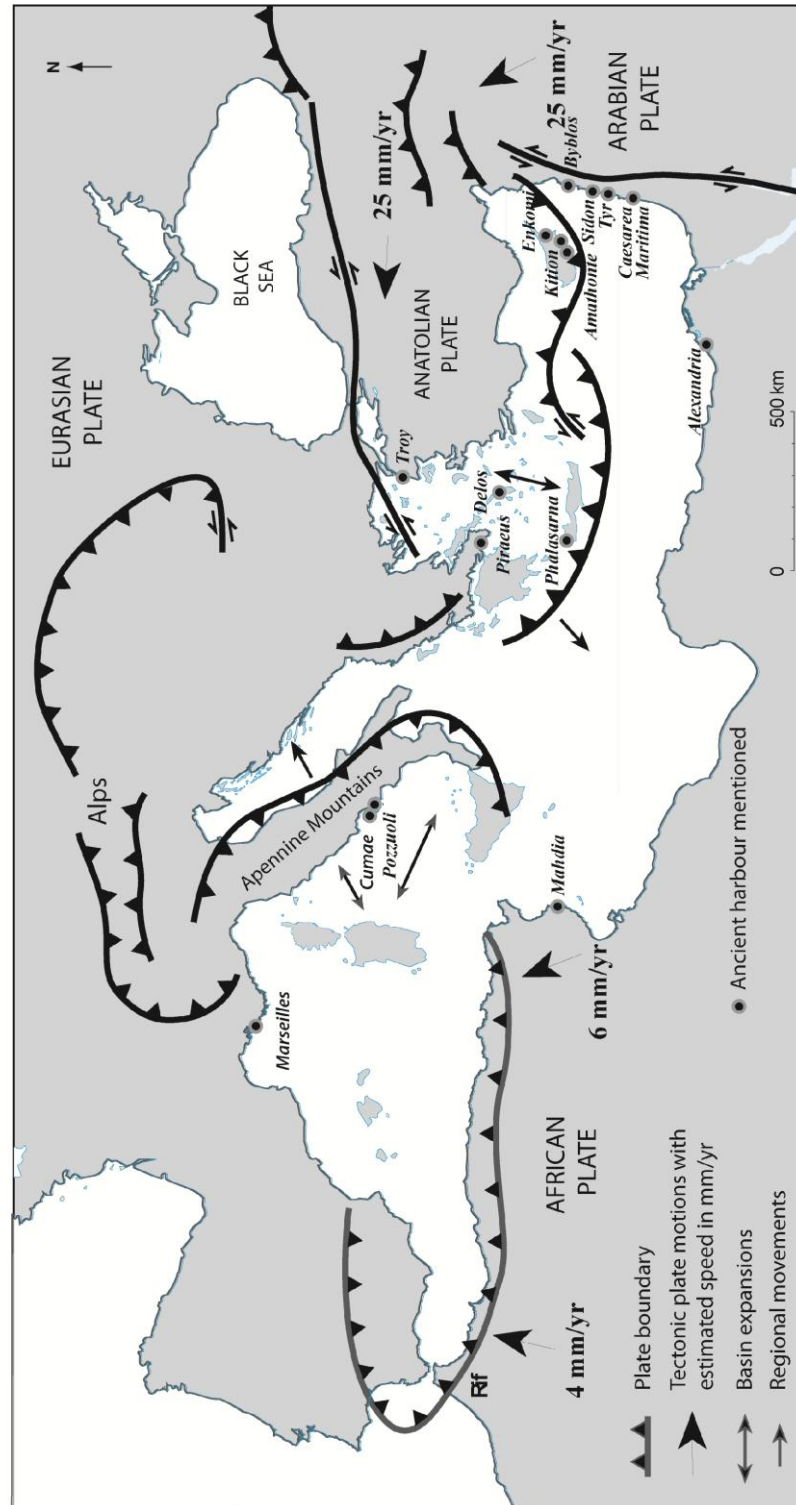
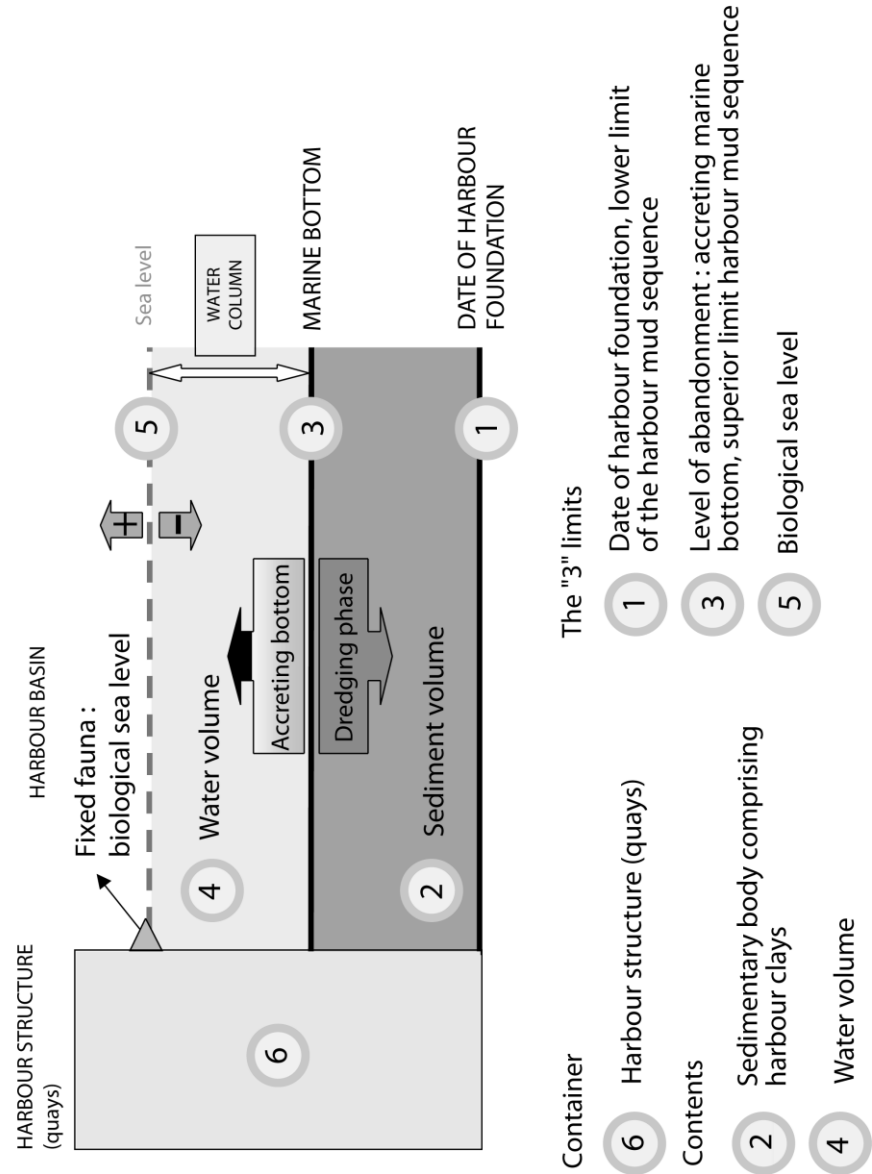


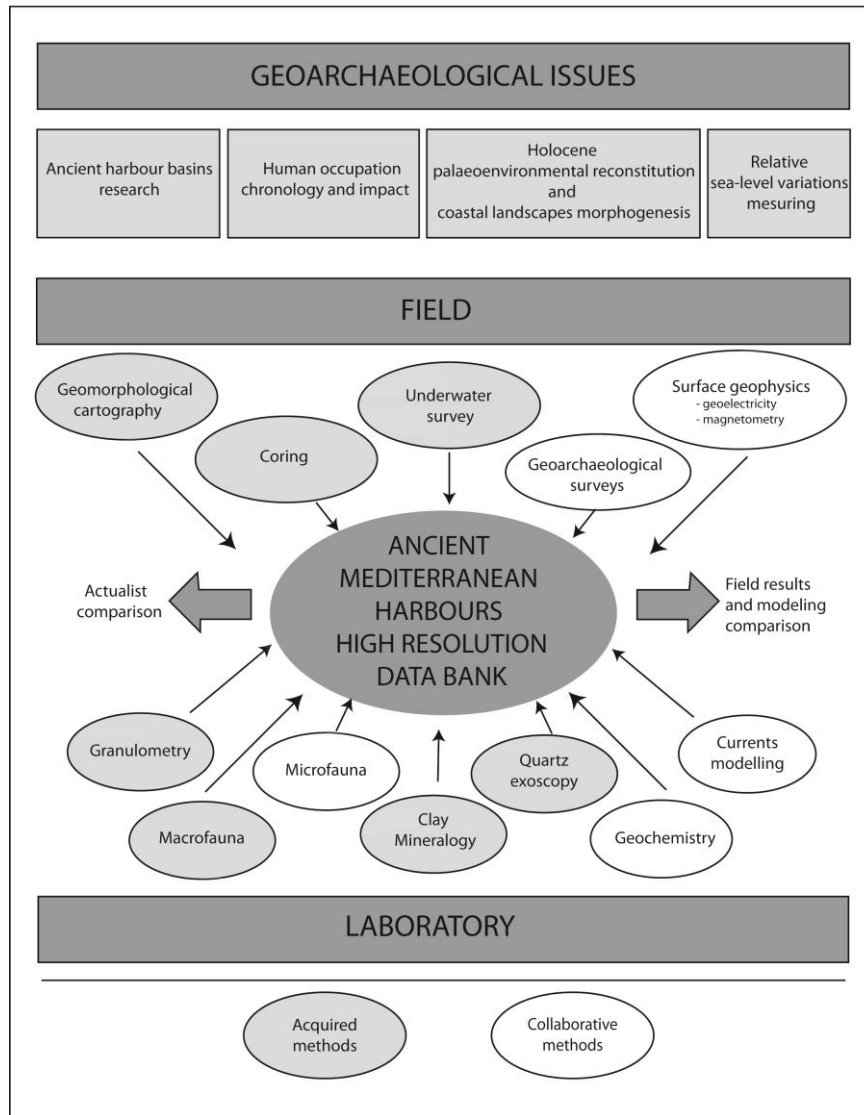


Figure 2: section of a functioning harbour basin



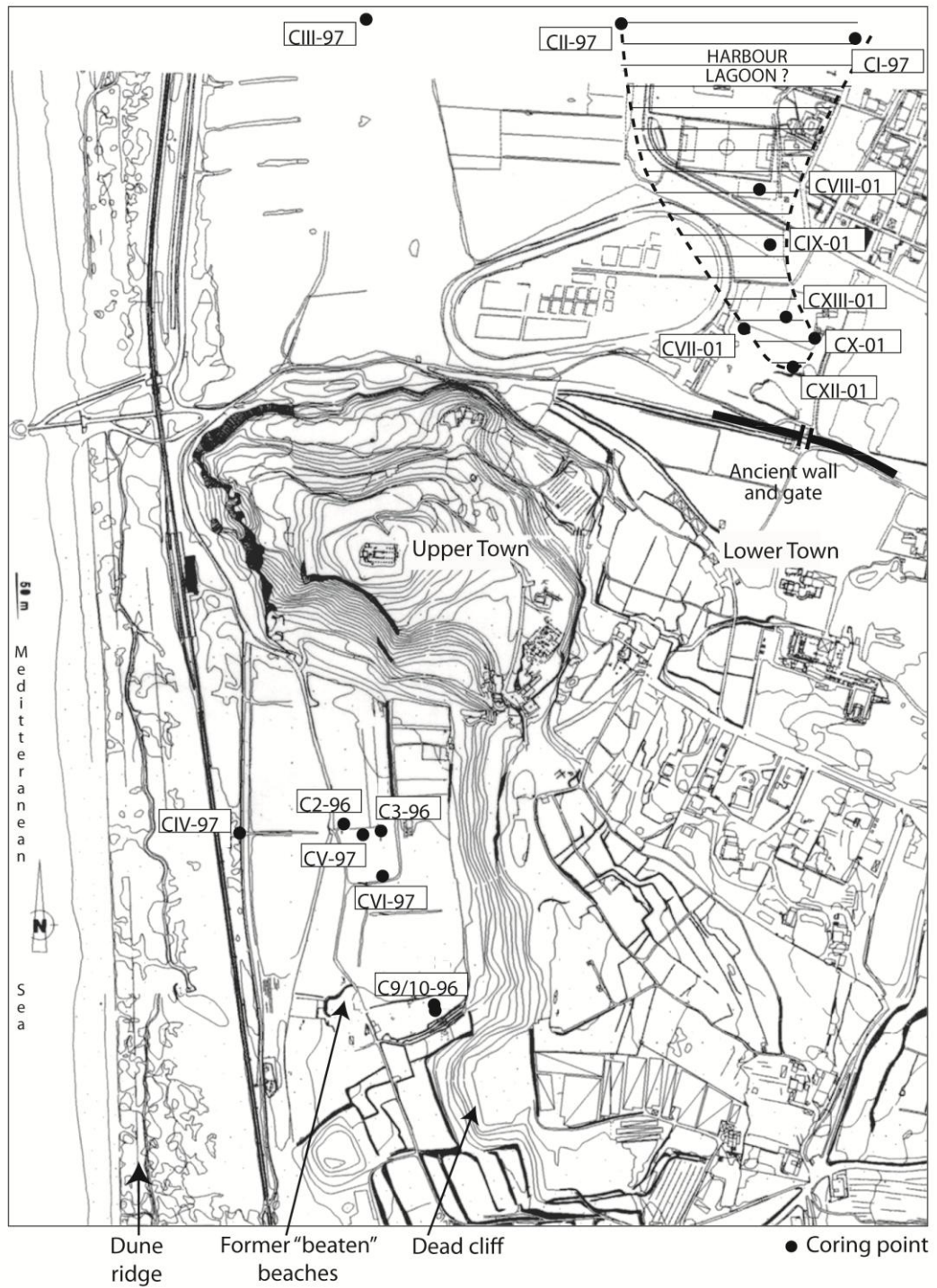
Goiran J.-Ph., Morhange C., 2001, "Geoarcheology of ancient mediterranean harbours: issues and case studies", eng. transl. E. Willcox, Topoi, vol. 11, fasc. 2, pp. 647-669.

Figure 3 : Developed issues and methodology



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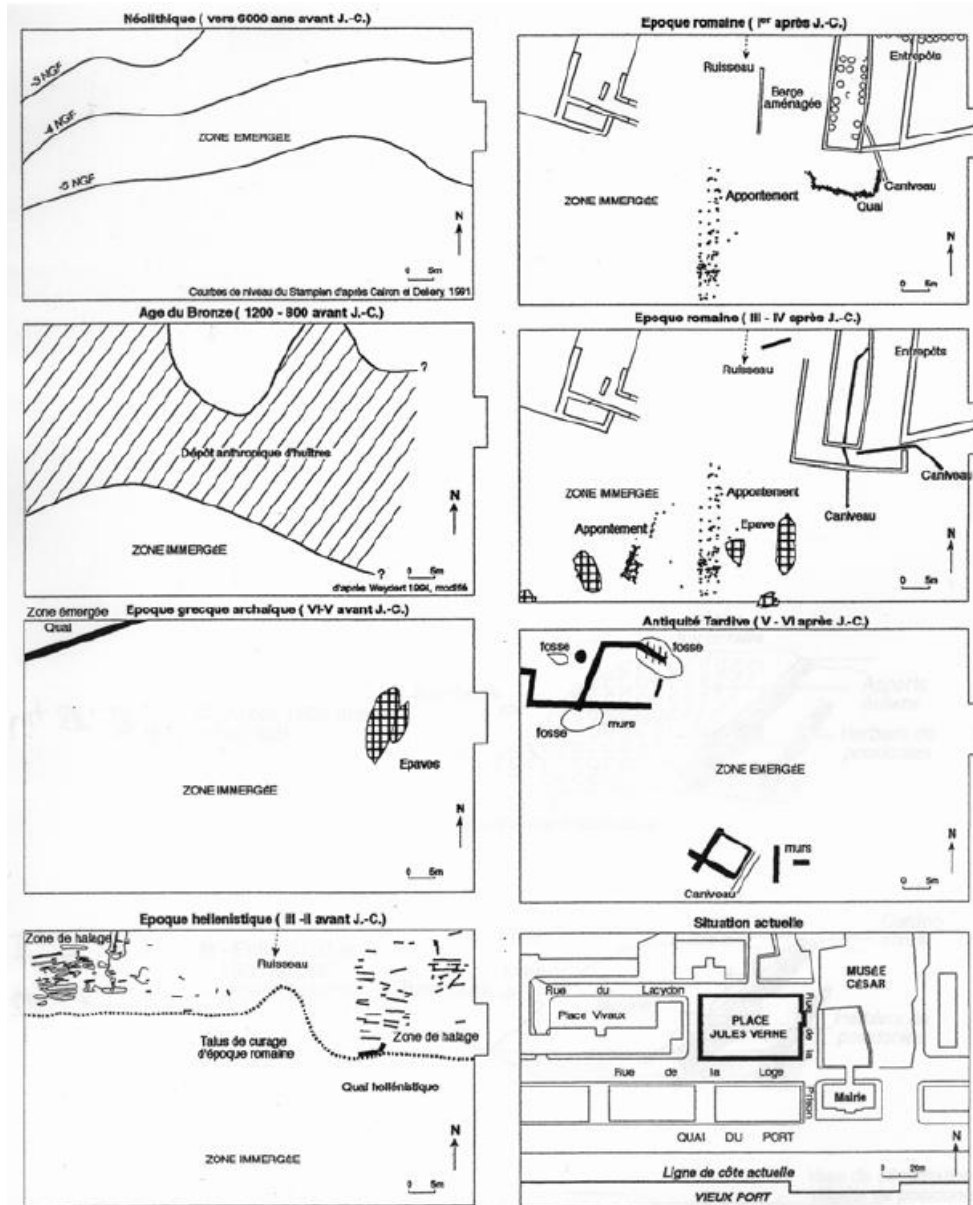
Figure 4 : Geomorphological sketch of the Cumae area (Italy)



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Figure 6 : shores evolution in Kition-Bamboula, Larnaca, Chypre since 3000 years

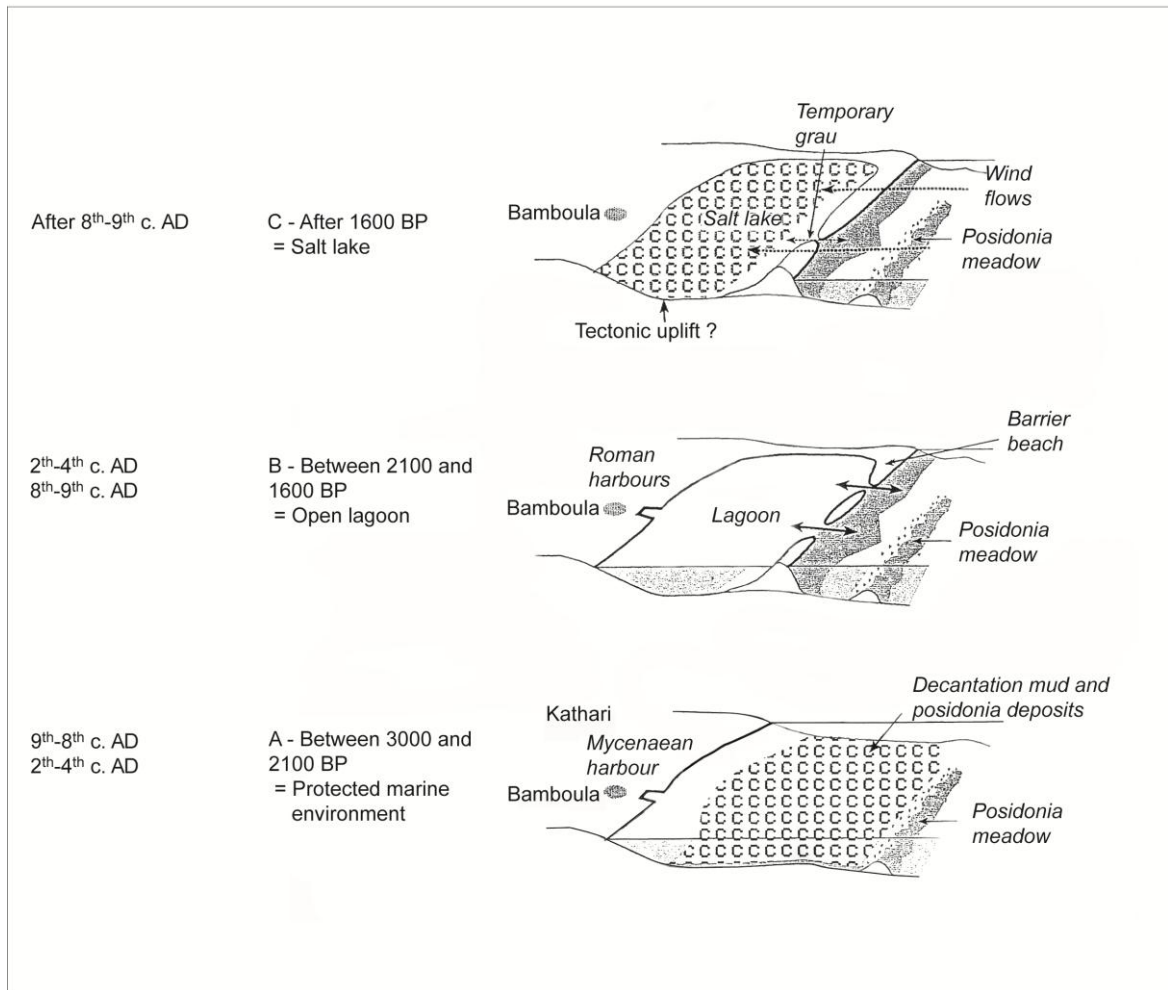
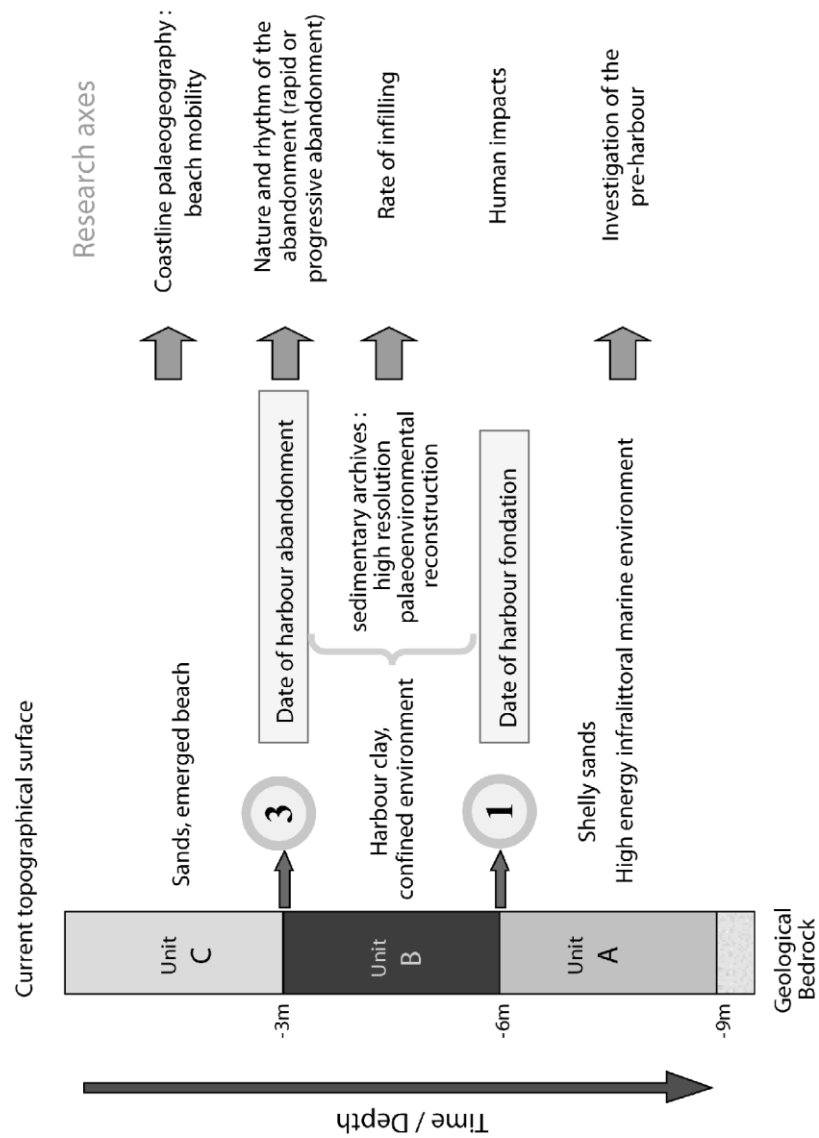


Figure 7: the three classical facies observed through borehole sampling in an infilled harbour basin of Antiquity



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Figure 8 : Examples of anthropogenic impacts studied in the Mediterranean since the Bronze Age

Type of impact	Main process	Examples of dynamic	Examples of studied site
<b>Granulometric</b>	"beaten" mode → calm mode	trapping of the fine particles siltation runoff on occupation surfaces	Sidon Alexandria Cumes
<b>Detrital</b>	erosion/accumulation accelerated rate	siltation : before IVe BC : 1mm/yr after IVe BC: 15mm/yr "urban" erosive crisis: speed X 15	fondation of Alexandria
<b>Geomorphic</b>	progradation from terrigenous origin artificialisation	multiplication and artificialisation of the shoreline	Alexandria Fréjus
<b>Biological</b>	confinement	ecosystem modifications rheophilic species → filter-feeding species	Alexandria Kition
<b>Geochemical</b>	pollution heavy metals release	contaminations $^{206}\text{Pb}$ $^{207}\text{Pb}$	Alexandria

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